NEXT GENERATION 2D PLANAR BOLOMETER ARRAYS FOR FAR-IR AND SUB-MM ASTROPHYSICS

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ABSTRACT

For future far-infrared and submillimeter astrophysics missions like SAFAIR (Single Aperture Far Infrared Observatory) and SPECS it is essential to develop technologies for large format 2D bolometer arrays of ~1000x1000 pixels. Such arrays should (a) maximize the fill factor for the focal plane, and (b) allow the use of low-noise detectors that scale well to large size, such as a Transition Edge Superconductor (TES) with multiplexed SQUID readouts. We have developed such a planar technology without use of feedhorns. Our technology does not require complicated mechanical packaging. Furthermore, they are constructed using Si wafers and readily available technologies, such as deep reactive ion etching. Here, we present the design, fabrication of prototype arrays, and the mechanical characterization of these arrays.

INTRODUCTION

For future far-infrared (FIR) and Sub-mm astrophysics missions (SAFAIR, SPECS) it is essential to develop technologies for large format 2D bolometer arrays with array sizes in the range of 128x128 to 1024x1024 elements[1]. Such arrays should maximize the fill factor for the focal plane, be scalable to any size, and use low-noise multiplexable detector technologies, such as a Transition Edge Superconductor (TES) with multiplexed SQUID readouts. We have developed and demonstrated several crucial technologies that will enable us to build a new generation of 2D bolometer arrays, which has several advantages over other designs. Current bolometer designs include Pop-Up Detectors or PUDs[2]. PUDs don't scale well to large sizes, due to the intricate manual handling and assembly issues. Spiderweb bolometers[3] use feedhorns, and are always slower for mapping a given area. The SCUBA-2 consortium is using a different approach, with a front-illuminated rectangular Si frame (≈200µm high), with suspended bolometers on the bottom. Photons strongly interact with the dielectric frame, which reduces the focal plane coverage to about 80%, and may complicate the transmission spectrum, due to diffraction of the incoming radiation. Our 2D arrays avoid these difficulties. They (a) maximize the fill factor (>95%), (b) can be customized to specific wavelength ranges, (c) are scalable to large (>256^2 element) sizes, and (d) can be combined with transition edge superconducting (TES) detectors and SQUIDs. Our technology does not require complicated mechanical packaging (as for PUDs), superconducting VIAs, or indium bump bonding techniques.

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MUSHROOM BOLOMETERS

Design Considerations

The arrays are composed of space filling Si "mushrooms" absorbers. The top of the mushrooms act as support structures for absorbers (like Bi films), and the stems carry phonons to a detector mounted at the base of the stems. By varying the thickness of the mushroom top and stem height, we can customize the distance of $\lambda/4$ between the absorber and an integrated reflector formed at the lower end of the mushroom. This reflective back short increases the efficiency of the absorber, and eliminates dielectric losses (no visible frame). For broad-band application, such a reflector is unsuited. One key element is the use of single-crystal Si for the production of the mushrooms. This reduces significantly the heat capacity of the mushrooms, and therefore allows for very fast internal time constants. We produced blocks of mechanical prototypes of different sizes (0.25x0.25, 0.5x0.5, and 1x1 mm^2) with different width to length ratios of the stems on 4'' wafers (See Figure 1).

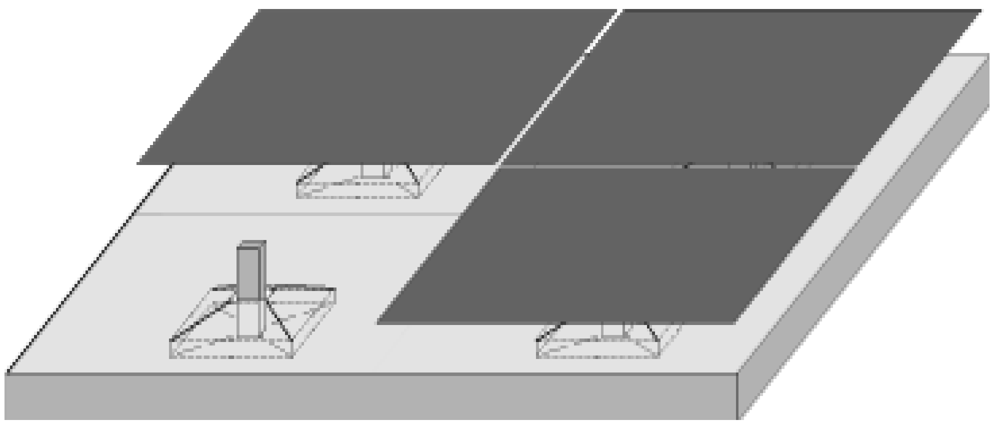

Figure 1: Conceptual 3D design of the new bolometer mechanical models. The top of the bolometers (dark grey) act a platform ofr the absorber, and the heat is passed through the stem down to the thermometer. One absorber was removed for clarity. Drawing approximately to size.

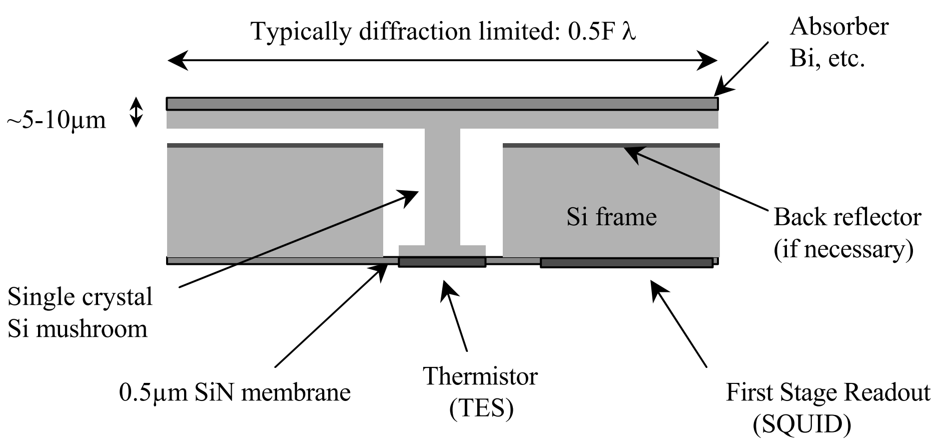

Figure 2: Conceptual side view of the new bolometers. Detectors (such as TES bolometers) and readouts can all be located on the bottom of the wafer. This avoids the need to use bunp-bonding and other technologies.

Array Fabrication

The first and most important task was to develop the specific production steps and processes of the mushrooms from single crystal Si wafers, and their bonding to a solid wafer. The stems are etched out using a deep reactive ion etch (DRIE). In the process, most of the wafer (~300µm thick) is removed, leaving behind a thin (10-50µm thick) Si membrane with the attached stems. The bottom of the stems was covered with a thin thermal oxide, which was successfully anodically bonded to an underlying borosilicate glass wafer. After the bonding, we applied a front-etch to etch out freestanding single crystal Si mushrooms (Figure 3). The anodic bond was easy to achieve, and is extremely strong. Anodic bonding requires only moderate temperatures of <300°C, and greatly simplifies the handling processes as compared to a Si–Si fuse-bonding which requires extremely clean polished surfaces and high temperatures.

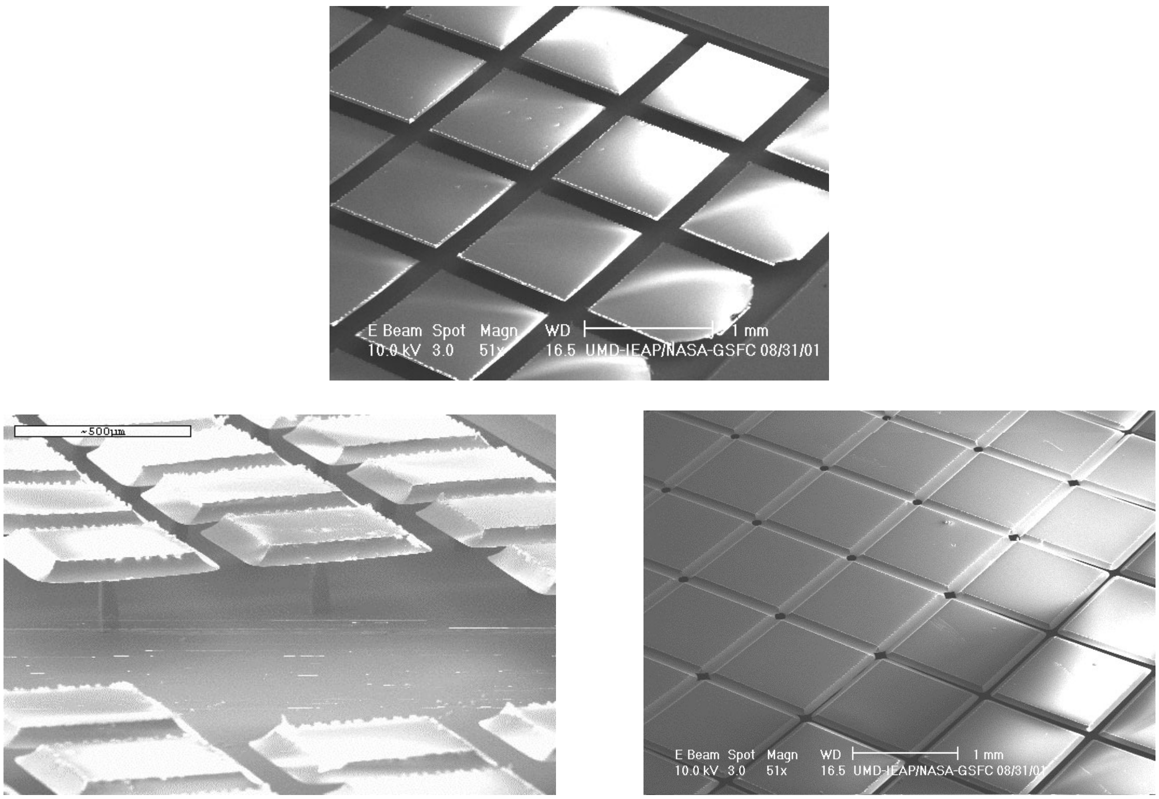

Figure 3: Three example of mechanical models of mushroom bolometers. On the top a 1x1mm² arrays (frame is visible on the top and right sides). The missing edges on the mushrooms on the right are due to overetching. . The gap between the mushrroms is larger than necessary, again because of overetching Left bottom: a 500x500µm² array, and right bottom: an underetched 1x1mm² array. These vairations in gap are due to the imperfections in our processing and can be eliminated using adequate etch stops.

Mechanical Characterization

Besides the quality of the anodic bond, we measured the structural integrity (stiffness and robustness) of individual mushrooms, and the possible mechanical failure modes (where do the mushrooms break? etc.). Figure 4 shows a finite element analysis model (FEMA) using MSC/NASTRAN of the stiffness of these mushroom bolometers on a fixed surface (not a SiN membrane). There are two fundamental excitation modes. One is a rotational mode around the center axis (i.e. stem), and a second mode that is the lowest frequency vibrational mode of the top of the mushroom. The calculations for a 500x500µm mushroom

10μm thick on a 20x20μm large stem show a resonant mode of approximately 76kHz (figure 4), while we measured ~85KHz for a similar mushroom with a thicker stem (figure 5). Attaching the mushrooms onto a SiN mesh reduces the resonance mode to about 5KHz.

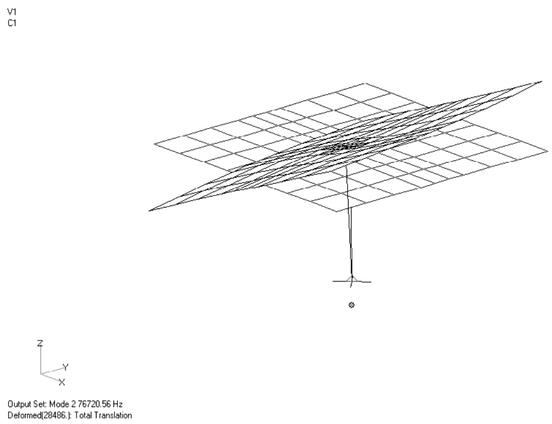

Figure 4: Calculated vibrational resonance mode (mode 2) for a mushroom n a fixed surface. The FEAM gives a resonance freuqncy of 76 kHz for a 500x500 μm mushroom.

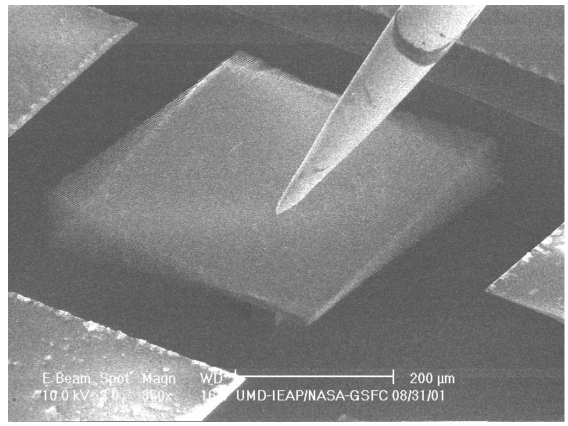

Figure 5: A time integrated photo of a tungston stylus that is resonantly exciting a 0.5x0.5mm^2 mushroom at a frequency of 85KHz. Note the node running from top left to bottom right, and the excitation of the mushroom top at the left and right sides of the mushroom.

FUTURE WORK AND CONCLUSIONS

We have build 30x30 element arrays of 500x500μm mechanical models. However, they can be scaled to almost any size, and wafers can be butted against each other. The possible integration of the SQUIDS onto the detector simplifies the overall design. Thus, it is possible to first build the mushroom structures, without the final front etch, which separates the individual mushrooms. This results in a robust package, which can be further processed to apply the TES detectors and SQUID first stage amplifiers. Furthermore, we are free to choose any absorbers, including epitaxially grown HgCdTe for use in soft x-ray bolometers.

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